Nuclear Instruments and Methods in Physics Research B 267 (2009) 2908–2917

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research B

journal homepage: www.elsevier.com/locate/nimb

Dual chamber laser ion source at LISOL

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ARTICLE INFO

Article history:
Received 10 April 2009
Received in revised form 20 May 2009
Available online 12 June 2009

PACS:
29.25
32.80.Fb
42.62.−b
52.70.La

Keywords:
Laser ion source
Ion guide
Resonance laser ionization

ABSTRACT

A new type of gas cell for the resonance ionization laser ion source at the Leuven Isotope Separator On Line (LISOL) has been developed and tested under off-line and on-line conditions. Two-step selective laser ionization is applied to produce purified beams of radioactive isotopes. The selectivity of the ion source has been increased by more than one order of magnitude by separation of the stopping and laser ionization regions. This allows the use of electrical fields for further ion purification.

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1. Introduction

For the production of short-lived radioactive ion beams often high-pressure noble gases are used as a stopping media for the nuclear reaction products: the ion guide technique that was pioneered in the early 1980s at the University of Jyväskylä [1,2] and the ion catcher technique implemented recently at in-flight radioactive beam facilities [3–7]. In both methods one tries to avoid the recombination of the stopped recoil ions. In the ion guide method, this is achieved by a fast evacuation of the ions from the cell by the gas flow through the exit hole. In the gas catcher method, which is mainly designed for in-flight separators, DC and RF electrical fields are used to prevent the ions from touching the walls of the gas cell and to move them towards the exit hole where the motion is taken over by the gas flow. Furthermore, the electrical fields separate the ions and electrons created during the stopping process and reduce the ion recombination. The high intensity of the incoming beam can cause space charge effects and reduce the efficiency [8–10]. Mainly because of its small recombination coefficient, only helium is used.

Opposite to the above mentioned methods, the operational principle of the laser ion source is based on an element-selective resonance multi-step laser ionization of neutral atoms that after production in a nuclear reaction are thermalized and neutralized in a buffer gas where a weakly ionized plasma is created by the primary beam, the recoil ions and the radioactivity. This method was developed at K.U. Leuven in the early 1990s [11–13], and is used since then at the Leuven Isotope Separator On Line (LISOL) facility (Belgium) to produce short-lived radioactive isotopes. Recently, it has been implemented at the IGISOL facility (Finland) [14,15]. For completeness, we note that laser ionization spectroscopy in a gas cell has been developed as well [16]. Depending on the nuclear reaction different types of gas cells have been used for proton-induced fission and light- and heavy-ion induced fusion evaporation. In these experiments helium or argon at 500 mbar pressure as a buffer gas are typically used, however argon is preferentially used because of the larger recombination coefficient and the larger stopping power for energetic recoils. In both fission and fusion gas cells the stopping/thermalizing and laser ionization zones are not separated physically [17,18]: stopping and laser ionization happens in the same gas cell. As a result the primary accelerator beam, recoils and radioactivity influence the plasma conditions in the laser ionization zone and the ions created by resonant laser ionization (laser/photo ions) at a distance of a few cm from the primary beam path recombine fast (on a ms time scale), see e.g. Fig. 4 in [18]. Furthermore, unwanted ions are present and create an isobaric background for the experiments [19]. To reduce the recombination of laser ions, the survival of non-resonantly produced ions and the creation of unwanted ions by different processes (see further), a

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0168-583X/$ - see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.nimb.2009.06.013

pulsed beam mode in anti-phase with the mass separator time gate was used. In this way the mass-separated ion beam was only transported to the detection set-up when the primary beam was not present [13].

There are several sources of non-selective ionization in the laser ionization zone; these are ion scattering off the primary beam creating a flux of energetic ions in the laser ionization zone and hard UV and X-ray radiation from the target/window material and from the buffer gas. The nuclear reaction products, especially in the case of fission, can also contribute to the weakly ionized plasma and unwanted ion creation in this zone. When the primary beam passes through the gas it transfers most of its energy to atoms via inelastic collisions. This energy is dissipated in the gas via the emission of δ-electrons and photons. The δ-electrons with energy up to a few keV have a short range in the gas (less than 1 mm) but they cause excitation of inner electrons of the buffer gas atoms. This excitation results in vacancy cascades with emission of Auger electrons and fluorescent photons. The keV energy photons can initiate further excitation and ionization [20,21]. The probability of emitting fluorescent photons is higher for heavier atoms. In case of argon gas about 12% of the deposited energy in the excitation of K-shell electrons goes to fluorescence and the rest to Auger electron emission [22]. The gas cell windows, made of molybdenum, give 76% of excitation energy in the X-ray region. The vacancies in the K and L shells cause also an electron-shake off process that leads to the creation of multi-charged ions (with maximum 4+ state for argon) [23] that emit hard UV radiation. Most of the energy is deposited in the beam path but the scattered ions, the photons and energetic reaction products ionize the gas at larger distance from the point of initial ionization and a low-density plasma is created far from the beam path. This causes recombination of laser-produced ions, thus reducing the ion source efficiency, and the creation of unwanted ions. Collection of the unwanted ions prior to laser ionization using electrical fields is prevented due to the space–charge effect present in the gas cell [8,18].

In this article we present a new gas cell with separated stopping- and laser-ionization chambers. In this design the laser ionization zone is not in direct view from the accelerator beam path and the trajectories of recoils. This should allow us to avoid recombination of laser-produced ions, to use the accelerator beam in DC mode and to collect not-neutralized ions before laser ionization using electrical fields.

2. Experimental setup

2.1. Dual chamber gas cell

The dual chamber gas cell for proton-induced fission is shown in Fig. 1. It consists of stopping and ionization chambers that are connected via an elbow channel. The stopped recoils are brought from the stopping volume to the laser ionization volume by the gas flow. The noble gas, purified down to the ppb level in a getter-based purifier, enters the gas cell via the ring slit that homogeneously distributes the gas across the cell. The inner diameter of the stopping chamber is 4 cm and its length is 6 cm. The accelerator beam enters the cell through a molybdenum foil of 4 μm in thickness. The target is installed on the tilted surface of the insert that is fixed in the stopping chamber. The angle between the target surface and the incoming accelerator beam can be changed. This angle equals to 16° for proton-induced fission of uranium-238 and 35° for heavy-ion induced fusion evaporation reactions. The shape of the insert guarantees a turbulent free homogeneous gas flow towards the elbow. This is confirmed by gas flow simulations as presented in Section 3.2.

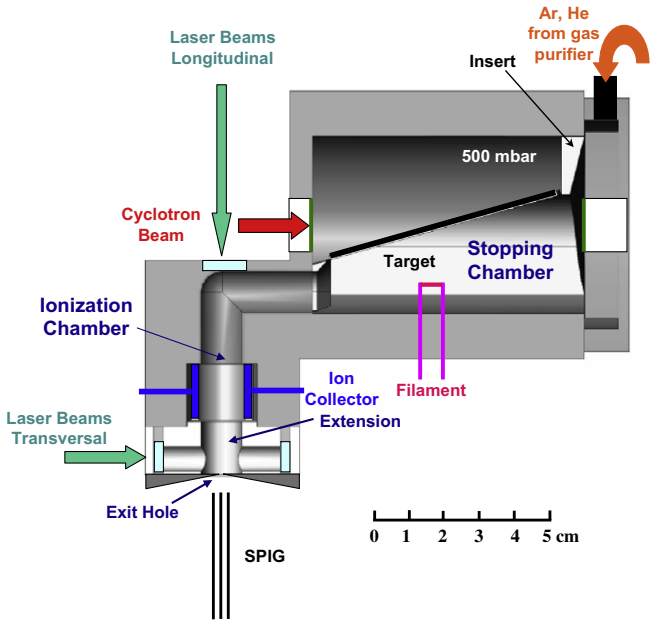

Fig. 1. A schematic drawing of the dual chamber laser ion source gas cell.

The laser beams enter the ionization chamber (30 mm long and 10 mm in diameter) longitudinally through a quartz window and ionize atoms along the chamber axis, Fig. 1. This laser beam path can be used to monitor the ion behavior in the ionization chamber. Atoms of stable nickel or cobalt isotopes can be produced inside the gas cell by resistive heating of corresponding filaments. An additional extension of 12 mm in length allows transverse laser beam entrance near the exit hole region. In this case an ion collector, located upstream, can be used to collect non-neutralized ions that come from the stopping chamber without collecting the laser-produced ions. The ion collector plates are shaped according to ring electrodes with an inner diameter of 11 mm. The evacuation time of the laser ionized volume (both longitudinal and transverse) at the exit hole diameter of 0.5 mm is bigger than the time between two subsequent laser pulses of 5 ms guaranteeing that all atoms have been irradiated by laser light. Ions leaving the gas cell are captured by a Sexupole Ion Guide (SPIG) and transported towards the mass separator.

2.2. Sextupole ion guide

The ions coming out of the cell have essentially the jet velocity of the carrier gas. The RF voltage applied to the SPIG rods provides radial confinement of the ions. A DC voltage up to 300 V of either polarity (+ or −) can be applied between the gas cell and SPIG rods. In normal running conditions the SPIG rods are negatively biased relative to the gas cell. In this case molecular ions that can be formed inside the gas cell after laser ionization are dissociated if the voltage is large enough [24,25]. In the case of a positive polarity, the ions from the gas cell are repelled. However in the longitudinal ionization mode part of the laser beam intensity goes through the exit hole and can ionize atoms outside the gas cell; only those ions created inside the SPIG are then transported towards the mass separator. This is the so-called LIST mode (Laser Ion Source Trap) proposed for a hot cavity in [26]. The results of our studies on the LIST mode, coupling a gas cell with an RF ion guide, combined with laser ionization in the RF structure and showing the possibility to do laser spectroscopy free of pressure broadening are presented in a separate paper [27].

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